
PHASE II

REVISED REPORT ON GREAT LAKES OPEN-COAST FLOOD LEVELS



Prepared by the U.S. Army Corps of Engineers
for the Federal Emergency Management Agency

Detroit, Michigan
April 1988

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N. Schwartz, Federal Emergency Management Agency, Region V
S. Tamulionis, U.S. Army Corps of Engineers, NCD
M. Todd, U.S. Army Corps of Engineers, NCD
C. Johnson, U.S. Army Corps of Engineers, NCD
J. Wanielista, U.S. Army Corps of Engineers, Detroit
R. Wilshaw, U.S. Army Corps of Engineers, Detroit
E. Megerian, U.S. Army Corps of Engineers, Detroit
R. Thomas, U.S. Army Corps of Engineers, Detroit
D. H. Lee, U.S. Army Corps of Engineers, Detroit
T. Pieczynski, U.S. Army Corps of Engineers, Buffalo
A. Coniglio, U.S. Army Corps of Engineers, Buffalo
C. Hessel, U.S. Army Corps of Engineers, Chicago
H. Kubik, U.S. Army Corps of Engineers, HEC
E. Thompson, U.S. Army Corps of Engineers, WES

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INTRODUCTION

The Federal Insurance Administration has adopted the 100-year flood as the standard for identification of flood hazard areas, in conjunction with the National Flood Insurance Program. Often the 10, 50, and 500-year flood levels are also of concern in dealing with flood control and sound flood plain management strategies. A two phase study was initially performed using water level information through 1974 to develop these flood levels for the Great Lakes and was published in 1977 as three booklets; Phase I, Phase II, and Appendices A and B of the "Report on the Great Lakes Open-Coast Flood Levels". In 1987, in consideration of the additional data collected since the original study was completed, and the extreme high water levels experienced in the Great Lakes since that time, FEMA requested an update of the previous study. The new study is entitled "Revised Report on the Great Lakes Open-Coast Flood Levels", and as in the past consists of Phase I and Phase II reports, and Appendices. The Phase I report presents the open-coast flood levels based on frequency curves of annual maximum instantaneous water levels. The levels were recorded by gages on the lakes, and adjusted

to reflect present diversion and outlet conditions. The Appendices contain the tables of adjustment factors, the frequency curves from which the various return period flood levels were derived, summary tables of the revised study results, copies of all correspondence pertaining to the development and review of the draft reports, and examples of flood level frequency determinations for Phase II areas.

In this document, the Phase II report, methods for determining the frequency of flood levels are presented for those locations not included in the Phase I Report. In general, these areas include the Connecting Channels, bays, inlets, and shoreline protected by islands. These areas are indicated on Plates 1 through 5 in the Phase I report of "The Revised Report on Great Lakes Open-Coast Flood Levels" and are listed here in Table 1. At some of these locations, the open-coast levels developed in the Phase I Report can be applied. At other locations, gage data with a short period of record are available, and separate flood level frequency determinations can be developed. Often, however, the short period of record is insufficient, and accurate determinations cannot be made without further development of the data. At the remaining locations, the open-coast flood levels cannot be applied, and there exists no systematic record of water level data. Given these conditions, the Phase II study presents:

- a. an analysis of the gage data on the Connecting Channels, and general guidelines for the application and interpolation of the results,
- b. a general approach to be used in determining the flood level frequency for areas not included in the Phase I Report,

TABLE 1 - PHASE II AREAS

Lake Superior

- Reach A - Whitefish Bay
- Reach B - Grand Island
- Reach B - Huron Island
- Reach B - Keweenaw Bay
- Reach C - Chequamegon Bay
- Reach C - Apostle Islands

Lake Michigan

- Reach A - Little Traverse Bay
- Reach A - Grand Traverse Bay
- Reach J - Green Bay
- Reach K - Straits of Mackinac

Lake Huron

- Reach G - Saginaw Bay
- Reach G - Thunder Bay
- Reach H - Straits of Mackinac
- Reach H - Les Cheneaux Islands
- Reach H - Drummond Island
- Reach H - St. Joseph Island

Lake Erie

- Reach K - Erie Harbor
- Reach W - Sandusky Bay
- Reach Z - Maumee Bay

Lake Ontario

- Reach B - Little Sodus Bay
- Reach C - Sodus Bay
- Reach C - Irondequoit Bay

Connecting Channels

- St. Marys River
- St. Clair River
- Detroit River
- Niagara River
- St. Lawrence River

c. methods of simulating or deriving flood level data for those gages having a short period of record, and

d. a suggested approach for developing flood level frequencies at locations where a systematic record of water level data is not available, and the open-coast levels cannot be applied.

FLOOD LEVELS OF THE CONNECTING CHANNELS

GENERAL

For the purposes of this report, the Connecting Channels of the Great Lakes are the St. Marys, St. Clair, Detroit, Niagara, and St. Lawrence Rivers. Many different variables, either separately or through interaction, can affect the water surface elevations of the Connecting Channels. These include the variability of flows in the Connecting Channels, the water surface elevations of the upstream and downstream bodies of water, and the extent of ice buildup. The effects of these variables are implicitly included in the flood level frequency analysis through the use of hourly instantaneous water level data collected at gages located on the Connecting Channels.

DATA

Official monthly mean and hourly instantaneous water level data, published by the National Ocean Service of the U. S. Department of Commerce,

NOAA, as recorded at gaging stations on the Connecting Channels, were used to derive the maximum annual flood levels. The same gages as used in the 1977 study were used in the new analysis, except for the Black Rock Canal and American Falls gages on the Niagara River. The Black Rock Canal gage is no longer functional, and was excluded from the study. The American Falls gage was also eliminated from the new study as the gage was relocated 400 feet upstream of the original site in 1976. Because of the steep slope of the Niagara River between the former and new location, the data could not be used as a continuous record. Ten years of record are available at the new location, however, this is too short of a period to develop a frequency curve. The American Falls gage can be included in future studies when the period of record is greater.

Over the period of record, the levels of the lakes have been significantly affected not only by nature, but by changes in the amount of diversions into and out of the Great Lakes Basin, changes in the outflow conditions resulting from regulation of Lakes Superior and Ontario, and dredging within the Connecting Channels. To account for the effects of the artificial changes on the historical lake levels, the recorded levels were adjusted to present conditions. Adjustments were derived from monthly mean lake levels obtained by routing the 1900-1986 net basin supplies through the Great Lakes under present diversion and outlet conditions. The adjustment factors are shown in Appendix A of the "Appendices to the Revised Report on Great Lakes Open-Coast Flood Levels". A more detailed description of how the adjustment factors were derived is included in the Phase I

report of the revised study. The adjustment factors derived for the lake gage data were applied to the Connecting Channels gage data using various methods. The adjustment factors for a lake were directly applied to channel gages which were close to and influenced by the lake, for example, Lake Superior adjustments were directly applied to data from the Southwest Pier. For the St. Clair River and the Detroit River gages, linear interpolations of the upstream and downstream lakes' adjustment factors were used, based on the distance the gages were from the downstream lake. No adjustments were applied to the gages located on the Niagara river, as all of the gages are located below the hydraulic control section of the outflow from Lake Erie. Table 2 displays for each Connecting Channel gage, the lake from which adjustment factors were applied, and where applicable, the linear interpolation factor.

METHOD

To develop the flood level frequency curve at each gage, a Pearson Type III frequency distribution was used in the analysis. The rationale for selecting this distribution is presented in the Phase I document of the revised study. The regional skew values which were derived in the Phase I analysis were also applied to the Connecting Channels. Thus, the frequency analysis of the St. Marys, St. Clair, Detroit, and Niagara River gages employed a skew value of 0.2, while the frequency analysis of the St. Lawrence River gages used a skew of 0.4.

Water surface profiles for the Connecting Channels were also developed, to be used as an aid in interpolating the results for those reaches between the gages. The profiles for each Connecting Channel are based on the 90%, 50%, and 10% frequency of occurrence of monthly mean flows determined from a flow-duration curve. The flow-duration analyses were based on the open water season (May through November) monthly mean flows, derived by routing the 1900-1986 net basin supplies through the Great Lakes under present diversion and outlet conditions.

RESULTS

The results of the flood level frequency analyses of data from the gages along the Connecting Channels are presented in Plates 1-6. The flood levels are referenced to International Great Lakes Datum, 1955, as well as Mean Sea Level Datum (Mean Sea Level Datum is equivalent to the National Geodetic Vertical Datum of 1929). When interpolating between the gages, the profiles shown on Plates 1-6 can be used as guides. However, any interpolated results should be verified as closely as possible by an on-site inspection of high water marks and other collected data.

As previously described, the profiles shown are for ice free conditions. If the area under study is susceptible to flooding caused by ice jams, the given water surface profiles may not provide a true guide for interpolation of results. During an ice jam, the normal flow in a channel is significantly reduced, raising the water surface elevation upstream of the ice jam, and lowering the elevation downstream. The change in the water

TABLE 2 - ADJUSTMENT FACTORS APPLIED TO CONNECTING CHANNEL GAGES

Connecting Channel and Gage	Interpolation Factor	Lake Adjustment Factors
St. Marys River		
Southwest Pier	none	Lake Superior
U. S. Slip	none	Lakes Michigan-Huron
St. Clair River		
Dunn Paper	none	Lakes Michigan-Huron
Mouth of Black River	0.93	Lakes Michigan-Huron and Lake St. Clair
Dry Dock	0.86	Lakes Michigan-Huron and Lake St. Clair
Marysville	0.75	Lakes Michigan-Huron and Lake St. Clair
St. Clair	0.50	Lakes Michigan-Huron and Lake St. Clair
Algonac	none	Lake St. Clair
Detroit River		
Windmill Point	none	Lake St. Clair
Fort Wayne	0.62	Lake St. Clair and Lake Erie
Wyandotte	0.33	Lake St. Clair and Lake Erie
Niagara River		
Niagara Intake	none	none
Ashland Avenue	none	none
St. Lawrence River		
Ogdensburg	none	Lake Ontario

surface profile depends on the severity of the ice jam and its location. Ice jams can occur where there is a sudden change in the river slope, at sharp bends, and locations where the river channel narrows. Under present channel conditions, the Connecting Channels most susceptible to flooding caused by ice jams are the St. Marys, St. Clair and the Niagara Rivers. Ice jams have occurred in the Little Rapids Cut of the St. Marys River, resulting in raised water levels in the Soo Harbor. On the St. Clair River, flooding due to ice jams can occur at various points from south of Harsen's Island upstream to Port Huron. On the Upper Niagara River, flooding due to ice jams has been reported along the East (Tonawanda) Channel. Some flooding has also been reported on the Lower Niagara River, upstream of the Ashland Avenue gage, in the Maid-of-the-Mist Pool. Ice jams have also formed from Niagara-on-the-Lake to Queenston-Lewiston. The other Connecting Channels, the Detroit and the St. Lawrence Rivers, are less prone to flooding caused by ice jams under the present channel conditions and plans of regulation.

METHODS FOR DETERMINING FLOOD LEVELS FOR AREAS EXCLUDED IN PHASE I

GENERAL

This section contains a discussion of the general steps to be taken in determining flood level frequencies at bays, inlets, and shorelines protected by islands not included in the Phase I report. Knowledge and

documentation of all relevant data, including previous reports, documents, and studies is a necessary first step.

The following is a list of basic data that should be obtained to determine flood level frequencies in Phase II areas:

- a. open-coast flood levels (Published in the "Revised Report on Great Lakes Open-Coast Flood Levels - Phase I", U.S. Army Corps of Engineers, Detroit District, April 1988.),
- b. recorded water level gage data, if available,
- c. adjustments to present conditions for monthly lake levels (Published in the "Appendices to the Revised Report on Great Lakes Open-Coast Flood Levels"),
- d. recorded historical high water marks,
- e. informal flood data from resident interviews, newspaper files, aerial photos, etc., and
- f. hydrographic charts and meteorologic data.

After the above data have been collected, the investigator must determine which of the methods listed below is applicable to the situation at the particular area under study.

DIRECT TRANSFER OF OPEN-COAST FLOOD LEVELS

An initial determination must be made as to the applicability of directly transferring the open-coast flood levels into the shore area under study. This transfer can be made when a thorough study of hydrographic

charts and high water marks indicates that the physical characteristics of the shore and lake bottom are such that additional wind setup above the open-coast flood level is not possible. Wind setup is defined in Phase I of the "Revised Report on Great Lakes Open-Coast Flood Levels". A comparison of the high water mark elevations, to the data from the nearest water level gage, would provide an indication as to the degree of wind setup. A site inspection by the investigator is also recommended, to verify the chart data and to check for special or changed conditions that may not be apparent from observing the charts.

FLOOD LEVEL FREQUENCY DETERMINATION USING LONG PERIOD GAGE RECORDS

If long period recording gage data are available for the Phase II area under study, the methods described in Phase I of the "Revised Report on Open-Coast Flood Levels" should be used to determine the flood level frequencies. Tables of adjustments are available in the "Appendices to the Revised Report on Open-Coast Flood Levels", to convert recorded gage data to present conditions for each lake. Judgement is required to determine what constitutes a long period of record for a given gage. Leo R. Beard includes a good discussion of the significance of a period of record in his "Statistical Methods of Hydrology". Through experience, twenty (20) years of recorded annual instantaneous peaks have come to be considered, in most cases, the minimum period of record acceptable for a frequency analysis. Factors to be considered include:

- a. the gage location, with regard to shoreline configurations, offshore bathymetry, maximum fetch length exposure, etc.,

b. the variation found in the recorded data as compared to gages in similar or neighboring locations,

c. the quality of the gage records with regard to the frequency of measurement, breaks or gaps in the record, etc.,

d. and the results of any frequency analysis as compared to those performed in similar or neighboring locations.

FLOOD LEVEL FREQUENCY DETERMINATION USING SHORT PERIOD GAGE RECORDS

The following three techniques have been suggested to extend the period of record at a gage, or to derive frequency curves at a gage by comparing the short period of record rises measured by the gage to the known long period of record monthly levels of the lake. Long period monthly levels are shown in "Great Lakes Water Levels, 1860-1985" published by the U.S. Department of Commerce, NOAA, National Ocean Service, or directly available from the National Ocean Service upon request. Technique 1 uses simulation to extend the short period of record at the gage of interest. This technique can be used when a strong correlation exists between the long period of record, annual maximum monthly mean lake levels and the annual maximum instantaneous levels at the short period of record gage. Technique 2 can be used to determine flood level frequencies without extending the short period of record data through simulation. This method can be used when a poor correlation is found using Technique 1. Technique 3 can be used when a short period of record gage has monthly mean water levels which are correlated with those of a nearby gage with a long period of record.

a. TECHNIQUE 1. This method uses a regression analysis to develop a relationship between the annual maximum instantaneous water level recorded at a gage and the corresponding annual maximum monthly mean recorded at the corresponding lake. This relationship is then used to simulate the annual flood levels for that gage site from the annual maximum monthly mean lake levels adjusted to present conditions. Frequencies of simulated levels are then determined as described in the April 1988 "Revised Report on Great Lakes Open-Coast Flood Levels - Phase I".

This procedure may not be applicable to all gage sites. The correlation between the annual maximum instantaneous water level of the gage of interest and the annual maximum monthly mean of the lake is dependent upon local hydrographic and meteorological conditions at the gage site. Often, a correlation cannot be determined or the correlation is very weak. Correlation techniques and examples are presented in "Statistical Methods in Hydrology" by Leo R. Beard.

b. TECHNIQUE 2. This method, called coincident frequency analysis, was proposed by H. E. Kubik, of the Hydrologic Engineering Center, Davis, California. It derives the annual maximum flood level frequency curve by combining the frequency curves of long period of record monthly mean lake levels with the frequency of annual maximum rises recorded at the short period of record station. In general, the procedure is as follows.

(1) Determination of a wind setup frequency curve at the station of interest.

(2) Determination of a lake-stage duration curve based on monthly mean lake levels.

(3) Computation of a total level frequency curve for several selected mean monthly lake levels.

(4) Computation of the frequency for a given maximum level by weighting the exceedence frequency by the percent of the time the monthly mean level is expected to be at the selected monthly mean level.

Complete documentation of this method and an example is contained in "Procedure for Computing Frequency of Maximum Lake Levels", by H. E. Kubik, H-39, December 1974. This paper is available from the Hydrologic Engineering Center upon request and is included in Appendix E of the "Appendices to the Revised Report on Great Lakes Open-Coast Flood Levels".

c. **TECHNIQUE 3.** This method was developed by the firm of Johnson and Anderson, Pontiac, Michigan, for use in their Flood Insurance Studies. The detailed step-wise procedure of the method is shown below.

(1) Determine monthly mean lake levels and short duration water level rises (wind setup) for each month from observed records of the short period of record gage at the site of interest.

(2) Compare monthly mean recorded levels between the long period of record and short period of record gages to establish a linear regression equation.

(3) Generate adjusted monthly mean lake levels for the short period of record gage by inputting the adjusted monthly mean levels at the

long period of record gage into the regression equation for the entire period.

(4) Calculate the mean and the standard deviation of the simulated monthly mean lake levels for the entire period of record.

(5) Determine the frequency curve of the simulated monthly mean levels for the short period of record gage from the equation of the normal distribution function.

(6) Pick out the maximum short duration water level rise for each year (one event per year).

(7) Determine mean and standard deviation of the yearly short duration water level rise for the short period of record gage.

(8) Calculate parameters of the gamma distribution function for the short period of record gage.

(9) Use the equation of the the gamma distribution function to calculate the frequency curve for the yearly short duration water level rises.

(10) Combine probabilities of mean lake levels and short duration water level rises to determine the annual frequency distribution.

(11) Determine the cumulative probability distribution for all lake elevations at the short period of record gage.

(12) Determine lake elevations at the short period record gage for the desired return periods by interpolation of the calculated values.

Documentation of this method and an example of its application can be found in Appendix E of the "Appendices to the Revised Report on Great Lakes Open-Coast Flood Levels".

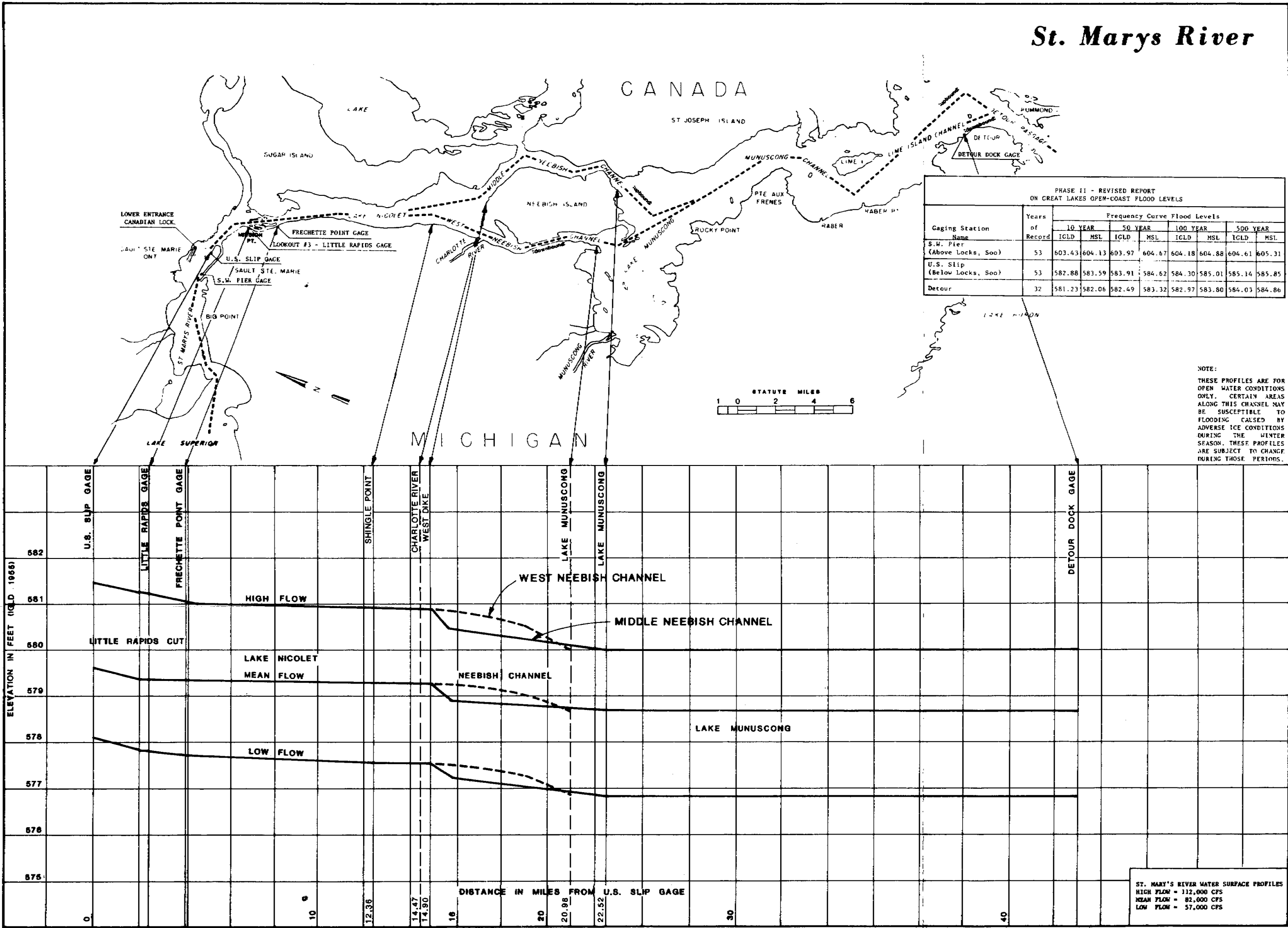
AREAS WHERE NO SYSTEMATIC RECORD OF WATER LEVEL IS AVAILABLE

In areas where no systematic water level record is available, and the open-coast flood levels cannot be applied, determining the water surface elevation associated with a given frequency is largely a matter of judgement. Development of flood levels at selected frequencies for these areas must first start with the collection of all data available. These data should include high water mark elevations, the dates and times that the high water occurred, the stages recorded at all gages in the area during the same storm event, the prevailing weather patterns, the open-coast flood levels, etc. An informal history of the water levels in the area of interest should be developed from interviews with residents, newspaper files, aerial photos, etc. The flood levels for various frequency floods at similar or neighboring gages should be tabulated and compared to the recorded high water mark elevations. From this set of data it may be possible to assign frequencies to various flood levels with some confidence.

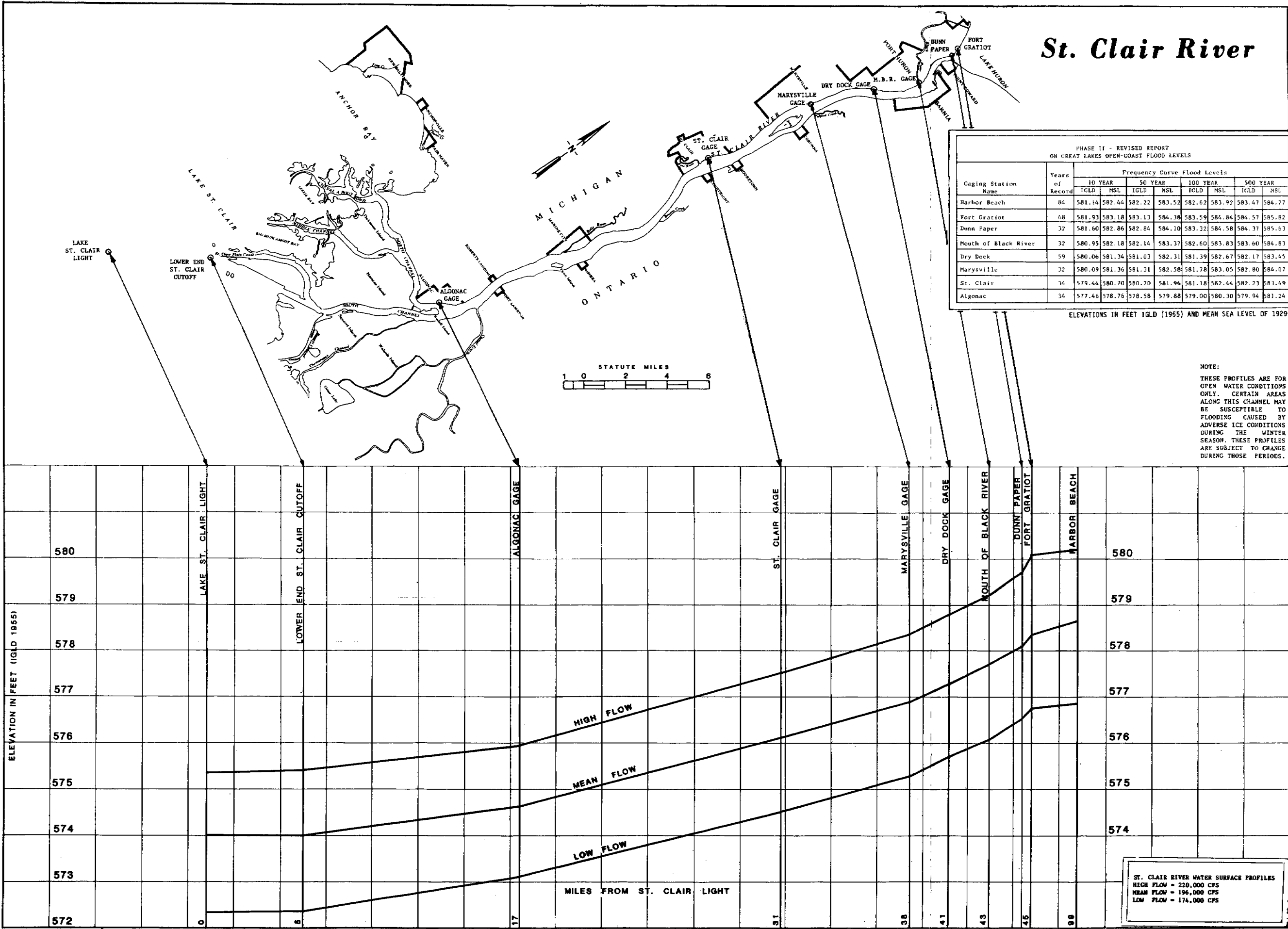
In addition to the collection of historic data, wind setup may be calculated for specific areas through the use of mathematical models. For example, if a windspeed frequency curve can be developed at a nearby gage, and transferred to the area under study, through the use of a model, a wind setup frequency curve may be generated. This curve can then be used in

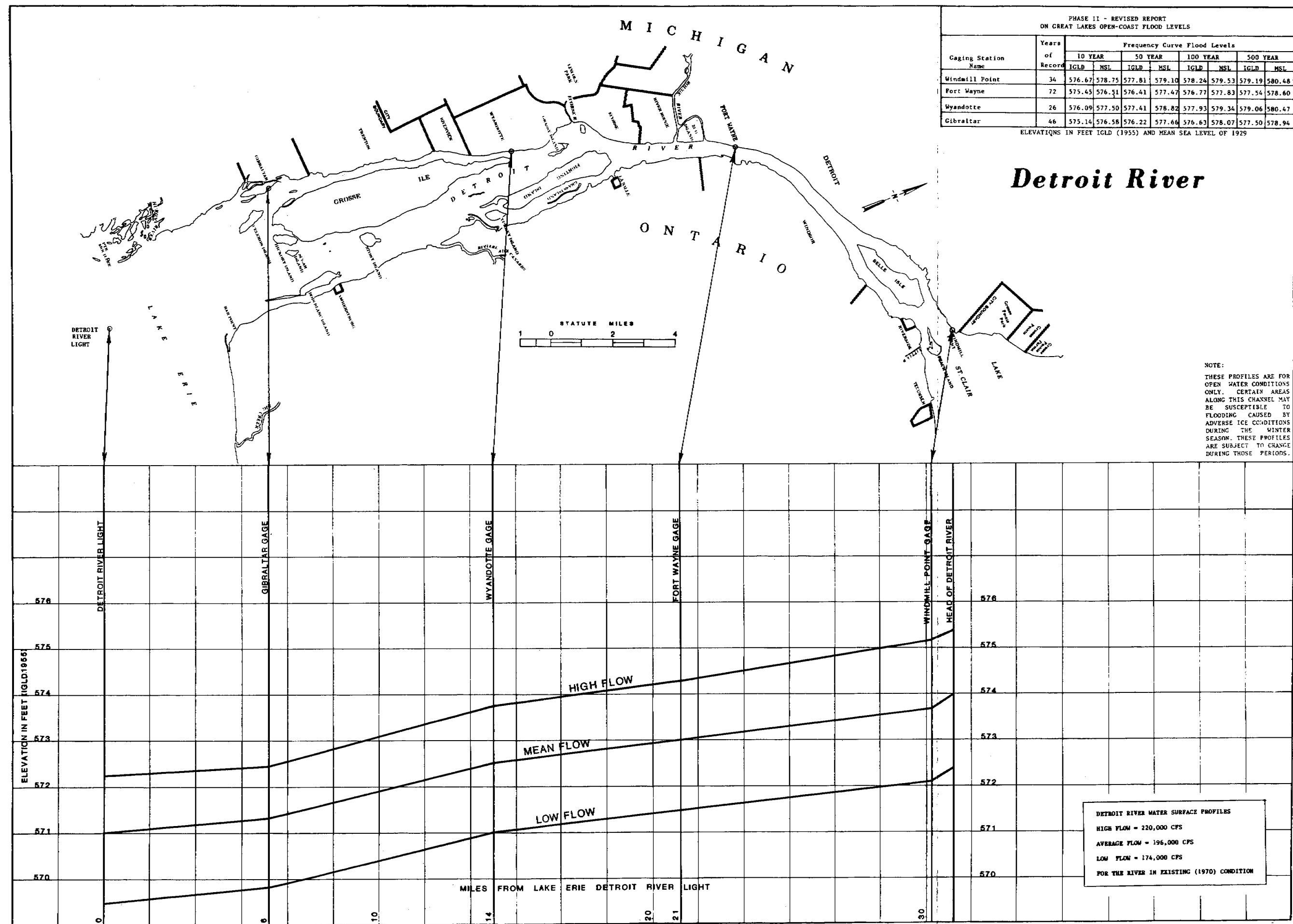
conjunction with one of the techniques presented in the previous section, to determine a flood water level frequency curve. The development of these models are too detailed to be presented here, but the "Shore Protection Manual" by the U.S. Army Corps of Engineers contains a discussion of these models and provides references to some which have been developed for the Great Lakes.

St. Marys River

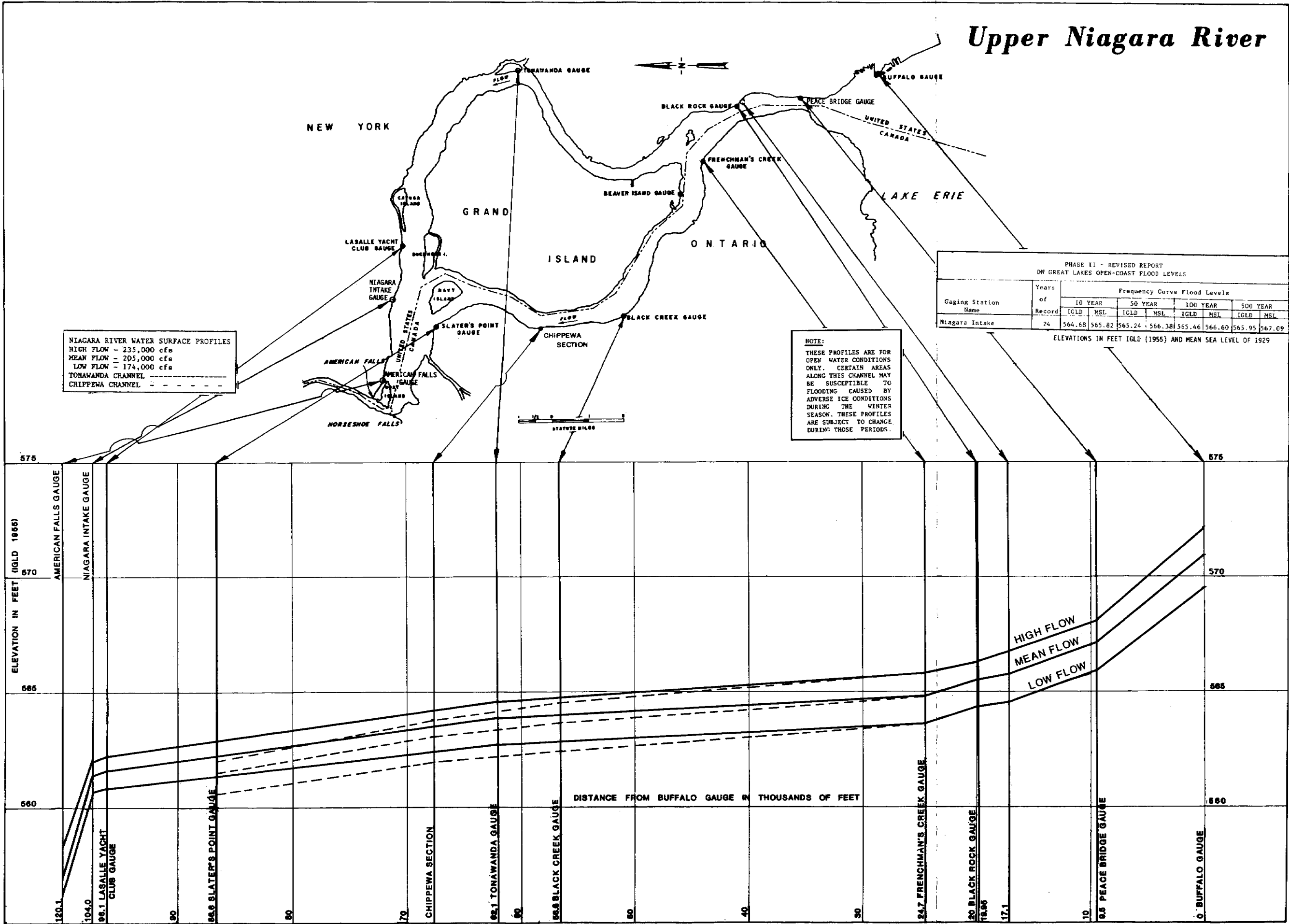


St. Clair River





Upper Niagara River



PHASE II - REVISED REPORT ON GREAT LAKES OPEN-COAST FLOOD LEVELS									
Gaging Station Name	Years of Record	Frequency Curve Flood Levels							
		10 YEAR		50 YEAR		100 YEAR		500 YEAR	
		IGLD	MSL	IGLD	MSL	IGLD	MSL	IGLD	MSL
Ashland Avenue	29	341.09	342.23	345.00	346.14	346.51	347.65	349.83	350.97

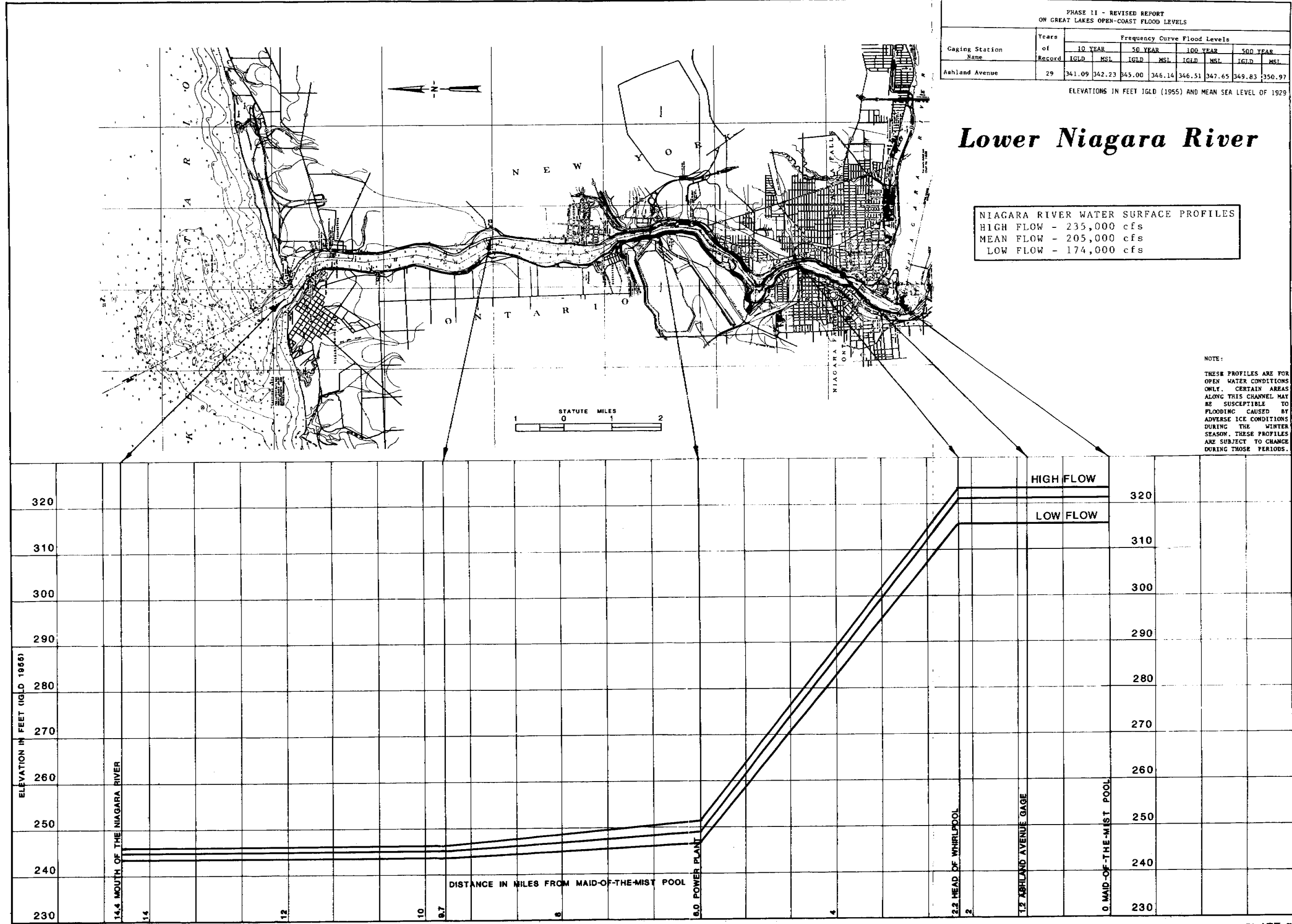
ELEVATIONS IN FEET IGLD (1955) AND MEAN SEA LEVEL OF 1929

ELEVATIONS IN FEET IGLD (1955) AND MEAN SEA LEVEL OF 1929

Lower Niagara River

NIAGARA RIVER WATER SURFACE PROFILES
 HIGH FLOW - 235,000 cfs
 MEAN FLOW - 205,000 cfs
 LOW FLOW - 174,000 cfs

NOTE:
 THESE PROFILES ARE FOR
 OPEN WATER CONDITIONS
 ONLY. CERTAIN AREAS
 ALONG THIS CHANNEL MAY
 BE SUSCEPTIBLE TO
 FLOODING CAUSED BY
 ADVERSE ICE CONDITIONS
 DURING THE WINTER
 SEASON. THESE PROFILES
 ARE SUBJECT TO CHANGE
 DURING THOSE PERIODS.

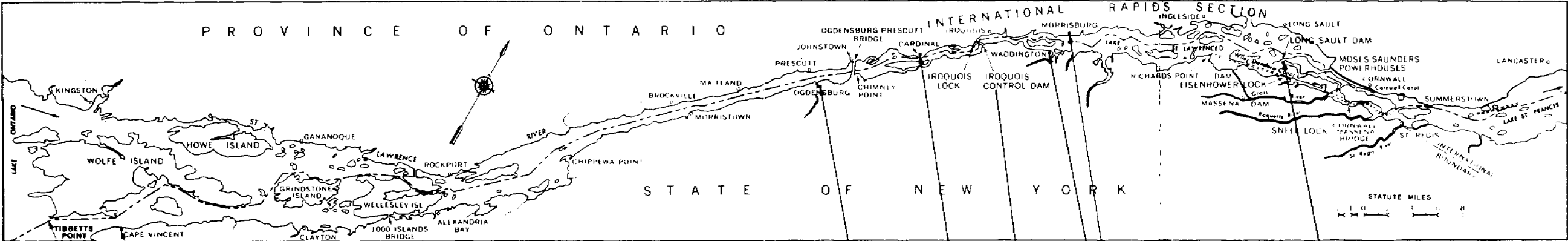


St. Lawrence River

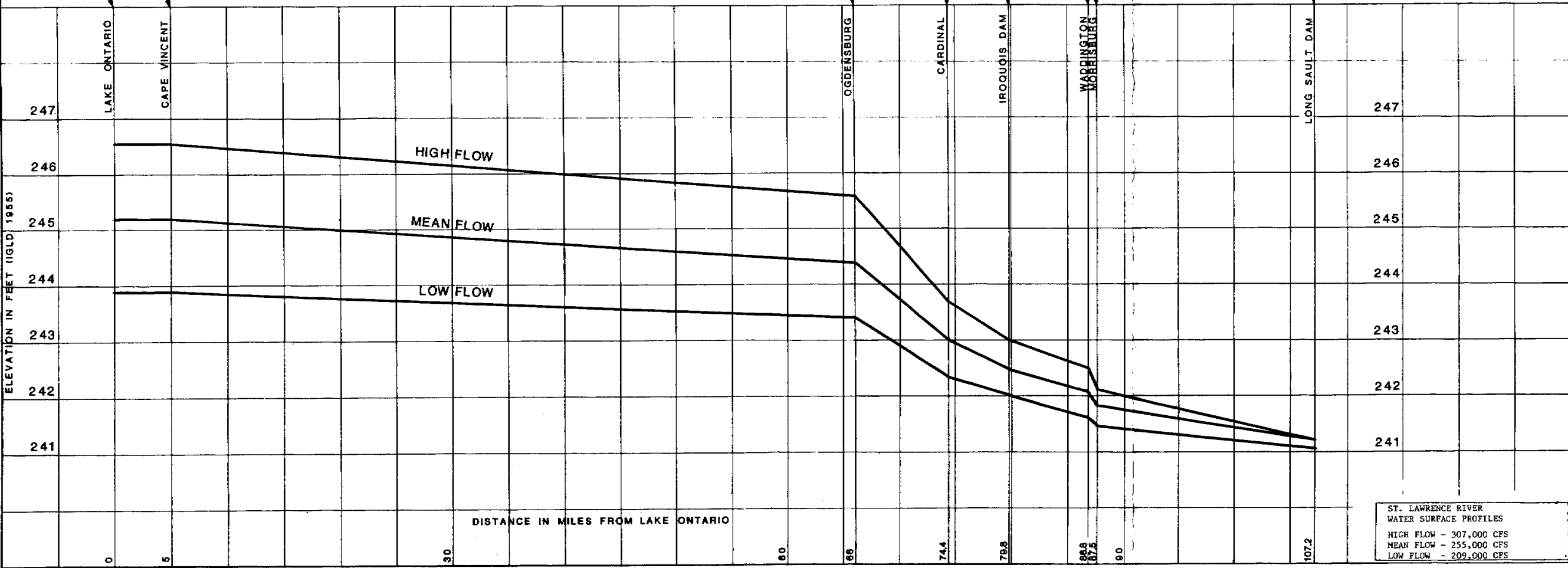
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Gaging Station Name	Years of Record	Frequency Curve Flood Levels							
		10 YEAR		50 YEAR		100 YEAR		500 YEAR	
		IGLD	MSL	IGLD	MSL	IGLD	MSL	IGLD	MSL
Cape Vincent	52	247.25	248.36	247.97	249.08	248.25	249.36	248.87	249.98
Ogdensburg	52	246.83	247.63	247.49	248.29	247.75	248.55	248.31	249.11

ELEVATIONS IN FEET IGLD (1955) AND MEAN SEA LEVEL OF 1929



NOTE:
THESE PROFILES ARE FOR OPEN WATER CONDITIONS ONLY. CERTAIN AREAS ALONG THIS CHANNEL MAY BE SUSCEPTIBLE TO FLOODING CAUSED BY ADVERSE ICE CONDITIONS DURING THE WINTER SEASON. THESE PROFILES ARE SUBJECT TO CHANGE DURING THOSE PERIODS.



GLOSSARY

Annual Maximum Instantaneous Water Level: The highest water level that was recorded during a year by a gage with a sampling frequency of an hour or less.

Annual Maximum Monthly Mean Water Level: The highest monthly average water level that occurred at a gage during a year.

Diversion: The transfer of water from one drainage basin to another.

Flood Frequency Curve: A graph relating flood water elevation and the probability of occurrence in any year.

Flow Duration Curve: A function describing the percent of time on average a given flow will be equalled or exceeded.

Frequency Distribution: A function describing the relative frequency with which events of various magnitudes occur.

International Great Lakes Datum (IGLD): Common reference datum for the Great Lakes area based on mean water level in the St. Lawrence River at Father Point, Quebec and established in 1955.

International Joint Commission: A single unit commission between the U.S. and Canada, created by the Boundary Waters Treaty of 1909, seeking solutions to the common problems in the joint interest of both countries.

Lake-Stage Duration Curve: A function describing the percent of time on average a given lake water level will be equalled or exceeded.

Master Gage: A lake level gage situated as to give an overall representative level of a lake, and usually having a long period of record.

Mean Sea Level (MSL): The datum referenced to the average height of the surface of the sea, found by averaging all stages of the tide over a 19-year period, at 26 stations along the Atlantic and Pacific Oceans, and the Gulf of Mexico. The establishment of the National Geodetic Vertical Datum included the 26 stations, thus referencing NGVD to MSL (See National Geodetic Vertical Datum).

Mean Monthly Level: The average water level for a month.

GLOSSARY (Cont'd.)

National Geodetic Vertical Datum of 1929 (NGVD): The nationwide reference surface for elevations throughout the United States. It was established by the National Geodetic Survey in 1929. Mean Sea Level datum is equivalent to NGVD of 1929 (See Mean Sea Level).

One Hundred Year Flood: A flood level that would be equalled or exceeded once in 100 years on average.

Open-Coast: Shoreline which is unprotected by the presence of islands and which is uninterrupted by bays.

Period of Record: The time interval in which data have been collected.

Regional Skew: A geographic area which displays similar skewing characteristics (see Skew Coefficient).

Rises above Mean Monthly Level: The difference in elevation between a maximum instantaneous water level and the mean monthly level (See Wind Setup).

Runup: The rush of water up a beach or structure, associated with the breaking of a wave. The amount of runup is measured according to the vertical height above still water level that the rush of water reaches.

Skew Coefficient A numerical measure or index of the lack of symmetry in a frequency distribution.

Still Water Level: The elevation that the surface of the water would assume if all wave action were absent.

Wind Setup: Vertical rise in the stillwater level on a body of water caused by piling up of water on the shore due to wind action.

Wind Setup Frequency Curve: A function describing the relative frequency with which wind setup of various magnitudes occur (See Frequency Distribution and Wind Setup).

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